

High Frequency Data Acquisition System for Space Shuttle Main Engine Testing **N88-13630**

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Through advancement of high speed analog to digital converters, fast I/O throughput of Winchester disk drives, and CPU multi-tasking, it is now possible to digitize analog data at very high sample frequencies for long periods of time. This advancement makes it possible to provide high frequency engineering data real time and eliminates some of the dependency on analog tapes. This paper discusses the high frequency data acquisition system developed for the SSME single engine test facility at the National Space Technology Laboratories (NSTL).

INTRODUCTION

Throughout the history of the Space Shuttle Main Engine (SSME) static testing program, engineers have been responsible for reporting on the dynamic characteristics of the engine and its components. However, the task of processing high frequency data has always been based on the existence and manipulation of analog tapes, resulting in time consuming techniques for providing engineering data. The complexity of the SSME, along with more aggressive test schedules, have defined a need for a better mechanism for processing dynamic data. Through the advancement of computer technology, it is now possible to digitally acquire (digitize) large amounts of analog data at high sample rates. Also, with the use of array processors, the time required to convert time domain data to the frequency domain by use of the Fast Fourier Transform (FFT) has been greatly reduced.

There are several benefits of acquiring high frequency data real time. There is no need for any tape head misalignment or tape speed compensation since analog tapes are not involved. The lengthy process of dubbing and shipping analog tapes is eliminated. By automating the acquisition/FFT process, the programs can operate with relatively few operator interventions. However, it is important to note that for dynamic data, analog tapes should not be eliminated as the primary recording device. For research and anomaly investigations, it is necessary to constantly change the analog/digital (A/D) parameters as well as input signal conditioning. In order to accomplish this, the tape must be replayed over and over. Some examples are input

adaptive filtering, looking at very high or very low frequency components, and electronic envelope detection.

Since much of dynamic data evaluation is done in the frequency domain, a data acquisition system must be able to not only acquire data but efficiently FFT the data. For a real time data acquisition system, it is not necessary to FFT the data "on the fly," since a large amount of time is being saved simply by not having to deal with analog tapes. However, the system must be able to compute FFT's utilizing some sort of firmware to facilitate a quick, efficient data transform process. The system developed for NSTL does this.

THE SPACE SHUTTLE MAIN ENGINE

The Space Shuttle propulsion system consists of two Solid Rocket Boosters and three SSME's. The SSME's are reusable, high performance, hydrogen/oxygen propellant rocket engines. The engines can be throttled over a thrust range of 50 to 111 percent of the designed thrust level. Each engine weighs approximately 7,000 pounds and can produce a sea-level thrust of 394,000 pounds. The engine operates at a chamber pressure of approximately 3,000 psia and has a design life of 27,000 seconds. The engines can be gimballed to provide pitch, yaw, and roll control during the orbiter boost phase.

Of primary concern to dynamicists is the health monitoring of the high pressure and low pressure turbopumps located on the engine. The high pressure fuel turbopump operates at 35,000 rpm providing over 63,000 horsepower. The high pressure oxygen turbopump operates at 28,500 rpm and delivers over 24,000 horsepower. The operating environment of the engine hardware makes it necessary to routinely analyze frequencies as high as 5 kHz in order to quantify the health status of the various engine components.

SSME SINGLE ENGINE TEST PROGRAM

SSME's have been undergoing static firings since 1975. Currently, there are three test stands active. Two stands are located at NSTL, Mississippi, approximately 50 miles due east from New Orleans, Louisiana, while the third is located at the Santa Susanna Flight Laboratory in California near Los Angeles. Two test stands are in development: B1 at NSTL and the technology test bed at Marshall Space Flight Center in Alabama. Over the past seven months, 85 static firings have occurred. These tests can last up to 750 seconds with a recent milestone achieved of a 1,000-second test.

Following each engine test (usually within 48 hours), engineers responsible for the monitoring of each engine subsystem meet together and present the data evaluation results. This input is used for component health evaluation as well as pre-test criteria for the next test. Some of the areas represented at the data reviews are: Combustion devices, turbomachinery, rotordynamics, systems performance, and dynamics.

For static firings, the engine is heavily instrumented, both with performance and dynamic measurements. Approximately 300 static measurements are active and are digitally acquired at 50 samples per second. From 90 to 160 high frequency measurements are active and are recorded on analog tapes. There are approximately 50 high frequency measurements which are critical to the data evaluation/review process.

DATA ACQUISITION AND PROCESSING PREVIOUS METHOD

For each engine test, all dynamic measurements are recorded on analog tapes. In the previous method for dynamic data processing, duplicates of these tapes were transferred to the NASA computer complex at Slidell, LA. There, the data were digitized for the entire test duration at 5,120 samples per second and stored on disk using a Hewlett-Packard 5451C Fourier Analyzer. The data were recalled in blocks of 2,048 points, converted to the frequency domain using the Fast Fourier Transform (FFT), then squared to form the power spectral density (PSD). Each PSD was written to magnetic tape, then transferred to Slidell's UNIVAC 1100/90 series mainframe. From the UNIVAC, users from MSFC in Alabama and Rocketdyne in California could access the data, producing various forms of plotted and tabulated output.

This system was the first step in providing a mechanism for the full test duration digitization of a measurement, thereby eliminating repetitive use of the analog tapes. However, due to limited performance on the 5451C, only 6 measurements could be processed at one time. For a 500-second test, it required 3 hours to acquire/FFT a 6 measurement data set. Also, Slidell had to wait for the analog tape duplicates to arrive from the various test facilities (NSTL is only 20 miles away; however, the A3 California test stand must ship the tapes by commercial air). The sample rate limited the frequency analysis to 2.5 kHz and the PSD format, while providing for all analysis necessary for data review purposes, prevented the use of special purpose signal processing techniques (i.e., cross correlation, transfer function, etc.). Finally, due to the large amount of time required to convert a measurement from the time domain to the frequency domain, only 15 to 25 of the more than 100 measurements could be processed in time for data evaluation/review support. The remaining measurements were processed by Rocketdyne at their Canoga Park facility on a time delayed basis.

In order to support the resumption of Space Shuttle flights, the engine program has adopted an aggressive testing schedule. The goal is to conduct 12 tests per month (in the past, the test rate was approximately 9 tests per month). This schedule mandated the development of a system to acquire high frequency data real time to circumvent the time consuming task of handling/processing analog tapes. This type of system would allow dynamicists the necessary time to complete the data analysis required for each post-test data review.

REAL TIME SOLUTION

The data acquisition system at NSTL is built around a Harris MCX super micro-computer. The CPU system base is also known as a MASSCOMP 5700. It contains two

Motorola 68020 CPU's residing on two multi-buses with 4 Mbytes of memory. It has two data acquisition processors (DA/CP's), which output digitized data through a custom written FORTRAN 77 queued transfer program to Fujitsu Eagle (387 Mbyte) disk drives. Through UNIX multi-tasking, each DA/CP can operate simultaneously, utilizing its own disk controller, thereby doubling the throughput of a single DA/CP system. Because of higher disk write throughput capability, the input sample frequency can be increased to 10,240 samples per second. Each DA/CP can acquire up to 48 measurements through its own sample and hold front end cards. This provides a real time test throughput of 96 measurements. Also, due to the large amount of disk storage available, test durations of any length can be supported.

Once the data have been digitized, the data are recalled and transformed using the FFT. This is done rapidly on the MCX due to the presence of a vector accelerator (array processor). The VA-1, as it is called, can compute a 1024 point FFT in 2.5 milliseconds. Also, the VA-1 can overlap DMA array transfers into and out of itself with mathematical operations on resident arrays. This is necessary due to the limited memory resident on the VA-1 (32k floating point words). By taking advantage of this overlap, the VA-1 can be kept constantly busy computing FFT's as well as transferring data back and forth from program memory. For a test duration of 500 seconds, it takes less than 30 minutes to complete the FFT transformation of 48 measurements (over 60,000 FFT's). Also, the MCX has two VA-1's present, and again with UNIX multi-tasking, data from both DA/CP's can be processed simultaneously effectively processing 96 measurements in the same amount of time as 48.

The front end of the real time system consists of DIFA anti-aliasing low pass filters. These filters have a cutoff frequency rolloff of 135 dB/octave. The filter programming chassis contains an RS-232 interface which allows the MCX to remotely set the anti-aliasing filter values. To prevent any DC override of the A/D converter, all inputs to the filters are AC coupled.

A high speed data transmittal network is becoming operational to transfer the FFT data from NSTL to host computers at MSFC and Canoga Park, CA (Rocketdyne). This system utilizes NASA's Program Support Communication Network (PSCN) and can operate up to 1.344 Mbaud. Also important is the fact that from NSTL, the PSCN can broadcast the data to MSFC and Canoga Park simultaneously. Current time estimates for the transmittal of high frequency data is 2 to 3 hours. This means that the real time system can complete 96 measurements before the previous analog tape method can complete 6.

CONCLUSION

By developing a real time data acquisition system, NASA has eliminated the time consuming, logistics laden task of handling/processing analog tapes for SSME single engine test dynamic data processing. The real time system will provide engineering data for a complete set of SSME instrumentation (approximately 100 measurements) within 4 hours following engine cutoff, a decrease of over 48 hours from the previous analog tape based system.